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Effect of tariffs on the performance and economic benefits of PV-coupled battery systems

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HIGHLIGHTS

- Pb-acid and Li-ion batteries are compared under three different retail tariffs.
- The battery ageing, i.e. capacity and discharge capability reduction is simulated.
- A dynamic tariff (1-h resolution) increases the battery discharge value up to 28%.
- A Li-ion cost of 375 CHF/kW h is required for Geneva for PV energy time-shift.
- This requirement becomes 500 CHF/kW h if demand peak-shaving is also performed.

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ABSTRACT

The use of batteries in combination with PV systems in single homes is expected to become a widely applied energy storage solution. Since PV system cost is decreasing and the electricity market is constantly evolving there is marked interest in understanding the performance and economic benefits of adding battery systems to PV generation under different retail tariffs. The performance of lead-acid (PbA) and lithium-ion (Li-ion) battery systems in combination with PV generation for a single home in Switzerland is studied using a time-dependant analysis. Firstly, the economic benefits of the two battery types are analysed for three different types of tariffs, i.e. a dynamic tariff based on the wholesale market (one price per hour for every day of the year), a flat rate and time-of-use tariff with two periods. Secondly, the reduction of battery capacity and annual discharge throughout the battery lifetime are simulated for PbA and Li-ion batteries. It was found that despite the levelised value of battery systems reaches up to 28% higher values with the dynamic tariff compared to the flat rate tariff, the levelised cost increases by 94% for the dynamic tariff, resulting in lower profitability. The main reason for this is the reduction of equivalent full cycles performed with by battery systems with the dynamic tariff. Economic benefits also depend on the regulatory context and Li-ion battery systems were able to achieve internal rate of return (IRR) up to 0.8% and 4.3% in the region of Jura (Switzerland) and Germany due to higher retail electricity prices (0.25 CHF/kW h and 0.35 CHF/kW h respectively) compared to Geneva (0.22 CHF/kW h) where the maximum IRR was equal to −0.2%.

1. Introduction

Many countries are reviewing their energy policies to position themselves on the global energy arena and address the "trilemma" of security of supply, affordability and decarbonisation [1,2]. Within this context, renewable energy (RE) technologies are in the spotlight since they have the potential for converting different world economies into sustainable in contrast to fossil fuels. After the accident at the Fukushima Diichi nuclear power plant in March 2011, the Swiss parliament decided to phase out all nuclear plants as part of a more comprehensive energy strategy which focuses on substantially reducing final energy and stabilising demand for electricity [3]. The Swiss Energy Strategy 2050 moreover foresees a reduction of greenhouse gas (GHG) emissions by 20% in 2020 and by a factor of 5 by 2050 and in comparison to 1990.

Several developments call for the use of energy storage (ES) across different sectors and scales in Switzerland within the new energy policy. Nuclear power plants will be mainly replaced by RE plants including hydropower, PV and wind generators, with

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Nomenclature

C	battery capacity, kW h
CF	cash flow, £
D_{ES}	proportion of the total demand met by a battery system
E_{char}	seasonal battery charge, kW h
E_d	seasonal demand of a single dwelling, kW h
E_{dis}	seasonal discharge, kW h
E_{PV}	seasonal PV generation, kW h
E_{PVES}	seasonal PV energy supplied to a battery system, kW h
h	hour
IRR	internal rate of return
k	generic year
$LCOES$	levelised cost of energy storage, CHF/kW h
$LVOES$	levelised value of energy storage, CHF/kW h
n	number of years the battery lasts
P	electricity price, CHF/kW h
PV_{ES}	proportion of the PV generation supplied to a battery system
r	discount rate (%)
Rev	battery revenue, (CHF)
$TLCC$	total levelised cost, CHF
Z	linear durability coefficient of a battery technology, %/EFC
η	round trip efficiency

Acronym

DT	double tariff
DynT	dynamic tariff
EFC	equivalent full cycles
ES	energy storage
Li-ion	lithium ion
PbA	lead acid
PV	Photovoltaics
PVts	PV energy time-shift
SOC	state of charge
ST	single tariff

Subscripts

nom	nominal
rt	retail
wh	wholesale

only the first offering matching capability. Specifically, 24 TW h of wind and PV generation are expected by 2035 [3] and the number of end users who own a RE plant will increase following the developments in other countries such as Germany, UK and Spain. Secondly, the last reform of the Swiss electricity market in 2009 included its partial liberalisation [4]. Customers with an annual consumption larger than 100 MWh can access the electricity market independently or freely choose their best electricity supplier. Market liberalisation is also envisaged for small consumers during this decade and new business models based on RE plants (heat and electricity), smart meters and different tariffs, thereby involving end users, utilities and/or ESCOs (energy service companies) are being explored [5].

The range of ES technologies available in the market and applications they can perform is wide and they have been compared in many review papers and reports [6–9]. Typically, ES technologies (and applications as a result) are classified using different criteria including electricity and heat storage, the duration of discharge and the scale (distributed versus bulked storage). Distributed ES is receiving marked attention due to the increasing penetration of RE technologies next to the locations of energy consumption [10]. There has been particularly strong interest in battery storage for managing PV generation in single homes since battery systems offer good capability to perform daily cycles while discharging for several hours with negligible self-discharge [11]. Many articles have been published in the last years on the technical and economic performance of battery systems. A high level of interest is sustained by the accelerated penetration of PV systems (in the last ten years, the cumulative installed capacity has grown at an average rate of approximately 50% per year [12]); increasing retail energy prices; and the decreasing prices and continually improved performance batteries.

Previous research which addressed the economic benefits of batteries systems for single homes mainly considered battery systems which were only charged by on-site PV plants and assumed constant round trip efficiency and durability [5,13–16]. A specific battery chemistry, typically either lead-acid (PbA) or lithium-ion (Li-ion), performing PV management by increasing the amount of local PV generation used at home was typically included in the study. The self-consumption as a function of the battery capacity was traditionally simulated, the economic benefits being calculated for the regulatory context of the respective country including Germany [5], UK [14], Portugal [15], Spain [16] and Belgium [13]. Local sensitivity analysis is typically the preferred technique used to tackle the uncertainty related with the modelling results depending on the input parameters, e.g., storage medium cost and electricity prices. The main novelties introduced by recent studies are: optimisation of both PV array rating and battery capacity (two degrees of freedom) without feed-in tariffs and calculation of economic revenue due to the difference between constant retail prices and constant wholesale prices [5]; calculation of the economic revenue depending on the investment year between 2013–2022 [5] and 2012–2021 [13] and for different remuneration schemes (subsidies, market prices and no fees at all); the inclusion of an environmental analysis [14]; the consideration of local and grid benefits for the different applications including self-consumption, reduction of the peak grid import, reduction of the peak electricity injected into the grid as well as integration of wind power from a national point of view [15]; and the combination of ES and active demand-side management managed by neural network controllers [16].

Focusing on communities ranging from a single home to a 100-home community, the performance and the economic benefits of PbA and Li-ion battery systems have also been analysed [17]. It was concluded that the levelised cost of meeting the demand load using PV energy decreased up to 37% for a 10-home community compared with the single home due to different benefits introduced by the community approach including less severe discharge rates, higher round trip efficiency and economy of scale. A different approach was also taken into account by Zucker and Hinchliffe [18] and domestic battery systems performing PV energy time-shift and arbitrage on the wholesale market were optimised from the perspective of an aggregator trading power on wholesale markets. The authors identified the optimum discharge time (5 h), power rating (40% of nominal PV capacity) and required capital cost (100–150 €/kW h). Tant et al. presented a multiobjective optimisation method for PbA and Li-ion batteries connected to three single-phase inverters in a low voltage (230/400 V) semiurban distribution grid. Three different applications were optimised, namely voltage regulation, peak power reduction and annual